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CHARACTERISTICS OF RECENT NORTHERN NEW ENGLAND TORNADOES

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1. INTRODUCTION

Historically, an average of four tornadoes occur each year across the northern New England states of Maine, New Hampshire and Vermont (Storm Prediction Center 2001). In recent years, tornado frequency across this region has diminished. Most northern New England tornadoes are classified as "weak" (F0-F1 on the Fujita scale), but "strong" tornadoes (F2-F3) do occur on occasion.

Our understanding of northern New England tornadogenesis is limited. They tend to be short lived, and often do not exhibit the radar and environmental characteristics of their Midwest tornado counterparts. Automated detection schemes have not performed well in this region either. The WSR-88D tornado detection algorithms have difficulty resolving tornado vortex signatures in northern New England (Cannon 1998). Manipulating algorithm adaptation data for enhanced detection has proven unsuccessful as well.

Questions concerning storm morphology further complicate the issue of early detection. For example, it is uncertain whether ascending or descending vortices (Trapp et al. 1999) are the primary mechanism for northern New England tornadogenesis. Without adequate conceptual models, the processes which trigger tornado development remain difficult to understand, and therefore challenging to predict. Also, the short lived, and low topped nature of these storms raise questions about whether we are using radar volume coverage patterns with sufficient spatial and temporal resolution for tornado detection in this region.

Other complications, such as line of sight visibility restrictions due to rugged terrain and the deeply forested and rural nature of the region, degrade the ability for visual observation of tornadoes. As a result, northern New England tornadoes remain difficult to warn for, with a probability of detection (POD) from 1994 to 2001 of only 0.16, and an average lead time of 1.3 minutes. The nationwide tornado POD during this time period was 0.62, with an average lead time of 10.1 minutes. The relative infrequency of northern New England tornadoes (25 tornado "county events" between 1994 and 2001, compared to a little more than 10,000 nationwide), further steepens the learning curve for forecasters.

To help mitigate the impact of detection limitations and improve situational awareness during the warning process, this study was conducted to produce a composite tornado day for northern New England. Environmental data will be examined and compared to the Johns and Dorr (1996) study of strong and violent tornado episodes within an expanded New England-wide domain. Frequency distributions will be provided of recent tornadoes across northern New England. Mesoscale and synoptic features will be reviewed and combined with radar information to derive a composite tornado environment. Topographical maps will be superimposed with tornado touchdowns to correlate varied terrain with tornadogenesis. Finally, commonly used convective parameters derived from modeled soundings will be examined for a tornado case.

2. DATA AND METHODOLOGY

The northern New England data set chosen for study begins in 1994. This was the first full year of continuous WSR-88D coverage in the Northeast. Also, the 1994-2001 tornado database permitted an application of the popular forecast and diagnostic software tool BUFKIT (Mahoney 2001).

Whereas Johns and Dorr (1996) studied strong and violent tornadoes in New York and New England, the database used in this study was limited to F1 and F2 tornadoes. There were no F3 or stronger tornadoes during this period (U.S. Dept. of Commerce 1994-2001). Except for a brief statistical review of tornado frequencies, F0 storms were not the focus of this study. This approach was chosen in an to attempt to examine synoptic and mesoscale features of tornadic storms which exhibited well defined damage paths and more distinct radar characteristics. These restrictions narrowed the database to 16 cases.

Surface and upper air analyses and METAR data were obtained from the National Climatic Data Center to develop atmospheric composites for the tornado cases. Upper air data were also used to produce proximity soundings nearest the time and space of tornado touchdown *(hereafter, time and location of tornado touchdown will be described as "T")*. Adjustments were made for advections between sounding times.

The schematic information will be useful for the development of forecaster pattern recognition. However, it is important to recognize smoothing of environmental features can adversely affect results. Studies in the Northeast have shown tornadoes can develop under a wide variety of conditions which can be masked with composite techniques (LaPenta 1995).

WSR-88D archive II, III and IV data were obtained from the National Climatic Data Center and surrounding NWS offices to examine radar characteristics and trends. A topographical map was superimposed with tornado touchdowns to examine the relationship of complex terrain with tornadogenesis.

BUFKIT proximity soundings were available for the 31 May 1998 case. ETA model profiles were selected from a site geographically nearby and environmentally representative of the tornado touchdown. Lifted Index, CAPE and helicity values were reviewed.

3. RESULTS

a. Tornado Frequency Distribution

From 1994 to 2001, twenty tornadoes of F0-F2 intensity struck northern New England resulting in an average of 2.5 occurrences per year (Fig. 1 and Table 1). This represents only 63% of the tornadoes normally expected during any given eight year period (Storm Prediction Center 2001) and demonstrates a recent trend towards lower tornado frequency.

It contradicts the expectation of increased tornado detection commonly associated with the deployment of highly sensitive Doppler radars and population increases.

The majority of tornadoes (1994-2001) occurred in Maine (12), which is not surprising as it represents the largest state in the domain. Seven tornadoes occurred in New Hampshire with only one in Vermont. During this period, half were F1s (10), with six F2s. When the Storm Prediction Center (SPC) tornado database is included (1950-1995), F1s outnumbered F2s by a larger margin of 132 to 42, respectively (Fig. 2). Most of the strong (F2-F3) tornadoes occurred in southern New Hampshire. The high frequency (70%) of weak (F0-F1) tornadoes is consistent with the national average (74%).

During the 1994-2001 period, tornadoes occurred in all months from May through October, except September. Adding the SPC database extended the tornado season to include March and November (Fig. 3). The majority of storms (85%) occurred during the "meteorological summer" (June, July and August). Tornado touchdowns during the 1994 to 2001 period tended to cluster evenly during the mid afternoon through early evening hours. Almost two thirds of the events (65%) occurred near the time of maximum diurnal heating of 18 to 00 UTC. Five of the 20 cases (25%) occurred during the morning through midday period of 12 to 18 UTC. No events occurred during the overnight period (06 to 12 UTC). The longer term SPC data indicates an even stronger diurnal trend (Fig. 4), with 79% of the tornadoes occurring between 18 and 00 UTC.

b. Environmental Data

Research has shown composite meteorological conditions and synoptic patterns associated with severe weather outbreaks in the Northeast (Johns 1982; Johns 1984; David 1976). However, these studies focused on northwest flow events across broad regions of the Northeast.

Environmental wind and temperature data from this study were compared to Johns and Dorr (1996) findings of strong and violent New England tornadoes produced in west flow environments (Table 2). Positioning of synoptic features were not compared since the two studies had differing domains. Unless otherwise specifically noted, our results were very similar to the Johns and Dorr findings. Surface, 850 mb, 700 mb and 500 mb data were examined for F1 and F2 tornado events in Northern New England. Composite synoptic features were produced from the cases. If a second tornado touched down from the same parent thunderstorm, the environmental data was only weighed once in the data set. This occurred 25% of the time (compared to 16% multiple "county events" using SPC data), which is a significant factor to consider during the warning decision process. This left 12 unique tornado days in the sample.

<u>Surface Conditions</u>

Seven out of 12 cases (58%) occurred along prefrontal boundaries in advance of cold fronts. Of the remaining cases, three were along warm fronts (25%) and two were considered warm sector events (17%). The F2 tornado days were evenly split between prefrontal troughs and warm fronts.

A distinct synoptic pattern was evident when plotting frontal positions with "T" for tornadoes in western portions of the research domain (Vermont and western New Hampshire in Fig. 1). The main synoptic features consisted of a relatively weak surface low pressure near Montreal and an associated cold front extending over central New York (Fig. 5). For eastern portions of the study (Fig.

1, eastern New Hampshire and Maine), the cold front extended over the Connecticut River valley from weak low pressure centered near Sherbrooke, Canada.

Surface conditions were analyzed to estimate air temperatures at "T". Temperatures averaged in the upper 70s (79˚F). These values are slightly cooler than those found by Johns and Dorr (82˚F). Five tornado days occurred with temperatures in the 80s, with six days in the 70s and one autumn event in the 60s. Dew point readings averaged in the upper 60s (68˚F). The vast majority of the sample (86%) had dew points between 66 and 71˚F at "T". No events exhibited minimum surface dew point readings below 60, including the early season (May) and autumn (October) cases. Prevailing surface winds were south (190˚) at 8 kt.

<u>Upper Air Conditions</u>

At 850 mb, the average low level jet at "T" was 33 kt for both F2 tornado cases and F1-F2 tornado days. Winds ranged from 20 to 40 kts with the mean position of the low level jet situated across southernmost New Hampshire and southwest Maine. The 850 mb flow exhibited a cyclonic west or southwesterly direction in all events (averaging 260˚) except one. The composite flow indicated both directional and speed shear within the surface to 850 mb layer. Average interpolated 850 mb temperatures at "T" was 14˚C, with a maximum of 17˚C and a minimum of 9˚C. Dew points averaged 11˚C.

700 mb winds were similar to the low level (e.g., 850 mb) flow, indicating little additional shear. Only modest intrusions of dry air occurred in the mid levels with dew point depressions averaging 6˚C.

At 500 mb, the composite flow regime depicted a westerly component (270˚) ranging from 30 kt to 70 kt at "T". The average wind speed was 42 kt, below Johns and Dorr findings of 50 kt. F2 tornado days also averaged 42 kt winds at 500 mb. Maximum jet location coincided with the 850 mb jet position over southernmost New Hampshire and southwest Maine. Most cases showed an open 500 mb trough with a neutral tilt axis over central New York state (Fig. 5).

Average interpolated 500 mb temperatures at "T" were -11˚C, with a maximum of -7˚C and a minimum of -16˚C. Dew points averaged at -17˚C, not quite as dry as the layer Johns and Dorr described (-22˚C).

c. Radar Data

WSR-88D archive data was available for five F1 and six F2 events. The characteristic of each cell was classified at "T". In five cases, the convection could best be described as "supercells", with three of these storms exhibiting the low topped characteristics of mini-supercells (Grant and Prentice, 1994). Three storms formed on a bow (two on the northern end and one on the southern end) with three tornadoes part of a broken line of convection.

Ten out of 11 cases showed a rotational signature. The failure to detect rotation in one tornadic storm was likely attributed to the radar beam overshooting the core of a shallow storm (echo top 25,000 ft) at a range of 63 nm. In most cases, the strongest rotational velocity was sampled on the lowest elevation angle. The average rotational velocity depicted on the 0.5˚ elevation slice at "T" was 27.8 kt with an average range of 52.4 nm. The values are consistent with thresholds of moderate mesocyclones using the Operational Support Facility (National Weather Service 1994) operator defined nomograms. However, the rotational signatures were shallow and lacked the time continuity required using this technique.

Automated detection software identified three mesocyclones from the database. Unfortunately, the Tornado Detection and Tornado Vortex Signature (TVS) algorithms (set at the default values) were unsuccessful in detecting TVSs. The average couplet diameter was only 1.4 nm, which produced an average shear of $.016s^{-1}$. Average observed shear values showed little difference for F2 tornadoes ($.018s^{-1}$).

Echo tops averaged 40,000 ft with Vertically Integrated Liquid values of 34 kgm^{-3}. The cells were relatively fast moving, consistently tracking from a west or southwest direction (averaging 260° at 33 kts), which in most cases, was similar to the mean wind flow.

d. Effects of Varied Terrain

Complex terrain features have been correlated with tornadogenesis in the Northeast (Bosart et al. 1996). North-south oriented valleys can increase low level shear and provide access to higher theta-e air for convection. In a review of F1-F2 tornadoes, 13 out of 16 events showed a southerly geographical exposure coincident with tornado touchdown (Fig. 6). This varied from well defined valley floors (such as the Connecticut River), to less pronounced topographical features. In three cases, southerly inflow was likely increased due to the close proximity of relatively frictionless lakes.

Most tornadoes occurred as convection exited the Appalachian Mountains. The longer term SPC tornado database (1950-1995) showed a similar clustering pattern. This region is dominated by a significant drop in elevation and often influenced by the nearby presence of the marine layer. Only three cases occurred a considerable distance from high terrain. One touchdown occurred over Lake Cobbosseecontee, ME and was likely aided by the combined effects of a southerly inflow over the lake and interactions with a sea breeze front (Cannon 1998).

4. BUFKIT: HIGH SHEAR-LOW INSTABILITY EVENT

BUFKIT allows for the examination of model derived, proximity soundings as compared to subjectively modified observed soundings. Although hourly forecast soundings contain model bias and errors, some of the error inherently found when manually creating soundings is mitigated. Producing a sounding which reflects near storm environment is a difficult task. By definition, the atmosphere will not be horizontally or temporally homogenous during severe weather situations (Brooks and Doswell 1994).

BUFKIT archives are limited for northern New England sites. This is especially true when attempting to match proximity soundings near "T". However, Springfield, VT BUFKIT files were available for the 31 May, 1998 Bennington, VT and Antrim, NH F2 tornadoes. This location is geographically similar and nearby the tornado path. Commonly used convective parameters of helicity, CAPE and lifted indices were produced from the 00 and 12 UTC, 31 May ETA run. The 00 UTC data was included for study since this model run is typically examined for the issuance of early morning severe weather outlooks.

Convection formed in a high shear, low instability regime. Low clouds inhibited instability as a warm front ahead of a vigorous surface low (988 mb) was forecast to move over the region coincident with "T". Forecast proximity soundings predicted a stable environment as CAPE values averaged 64 Jkg^{1} at "T" (parcel was lifted using the average temperature and dew point from the lowest 500 m of the atmosphere). Best lifted indices were +0.6 (parcel was lifted using the average temperature and dew point in the lowest 100 mb of the atmosphere). However, 0-2 km modeled helicity values of 763 m^2s^2 forecast a high shear environment. This helicity value is greater than those found associated with the LaPenta and Magalarus (1993) study of New York tornadoes. The combination of CAPE and helicity represents the extreme end of the scatter diagram described by Johns et al. (1993) for Eastern New York and New England tornadoes.

5. SUMMARY AND CONCLUSIONS

The incomplete understanding of the nature and morphology of tornadic storms in northern New England made this study compelling. Neither radar algorithms or operator expertise have demonstrated skill in tornado detection.

Climatology suggests tornado frequency has diminished in recent years. When a tornado does occur, there is a one in four likelihood of a second tornado from the same parent thunderstorm. They are usually warm season storms which occur during the maximum heating of the day.

The F1 and F2 northern New England tornadoes generally exhibited environmental characteristics similar to Johns and Dorr (1996) findings of strong and violent tornadoes in the Northeast. However, northern New England tornadoes were accompanied by a weaker 500 mb jet. The upper level low was usually open with a neutral tilt and situated over central New York state, with maximum winds situated over southernmost New Hampshire and southwest Maine. 700 mb plots indicated only a modest intrusion dry air in the mid levels. Directional and speed shear was mainly confined to the 850 mb to surface layer. Most storms formed along prefrontal troughs in advance of cold fronts. Average surface temperatures at "T" were not extreme, however dew points were consistently high.

Radar data indicated small diameter circulations originated from multiple storm types. Low level rotational values were consistent with moderate mescocyclones, but lacked time and depth continuity. Shear values were similar regardless of tornado intensity classification. Echo tops were relatively high and storms were moving at moderately fast speeds.

Preliminary results showed north-south oriented valleys and lakes appeared to correlate well with "T". Tornadic events tended to cluster in areas where storms exited the Appalachian Mountains.

Model derived soundings can mitigate subjective bias when computing convective parameters. An example of one case using ETA BUFKIT model soundings depicted low instability and high helicity values for two model runs prior to "T". This case demonstrated the need to expand forecaster mind set to a broad range of environmental conditions associated with tornadoes.

Storm surveys need to be actively pursued in order to differentiate tornadic and non-tornadic storms. Faster Volume Coverage Patterns (VCP), keying on low elevation angles are necessary for more robust sampling of the lower atmosphere.

Lastly, additional projects could include the creation of a forecast equation to predict the severity of convection. This has been accomplished with success using the Statistical Correlation and Regression program (SCORE) in New York State (Magalaras and Lapenta1997).

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REFERENCES

Bosart, L. F., A. Seimon, E. Bracken, J. Quinlan, K. LaPenta, and J. W. Cannon, 1996: Supercells Over Complex Terrain: The Great Barrington tornado of 29 May '95. *Preprints, 15th Conf. on Weather Analysis and Forecasting,* Norfolk, Amer. Meteor. Soc., 19-23.

Brooks, H. E., and Doswell III, C. A., 1994: On the environments of tornadic and nontornadic mesocyclones. *Wea. Forecasting,* 9, 606-617.

Cannon, J. W., 1998: Modifying the mesocyclone detection algorithm: The missing Lake Cobbosseecontee Maine tornado. *Eastern Region Technical Attachment No. 98-3*, National Weather Service, NOAA, U. S. Dept. of Commerce, 9 pp.

David, C. L., 1976: A study of upper air parameters at the time of tornadoes. *Mon. Wea. Rev.*, 104, 540-545.

Grant, B. and Prentice, R., 1994: Mesocyclone characteristics of mini supercell thunderstorms. *Preprints, 17th Conference on Weather Analysis and Forecasting*, Norfolk, Amer. Meteor. Soc., 351-355.

Johns, R. H., 1982: A synoptic climatology of northwest-flow severe weather outbreaks. Part I: Nature and significance. *Mon. Wea Rev*., 110,

Johns, R. H., 1984: A synoptic climatology of northwest-flow severe weather outbreaks. Part II: Meteorological parameters and synoptic patterns. *Mon. Wea Rev*., 112, 449-464.

Johns, R. H., J. M. Davies, and P. W. Leftwich, 1993: Some wind and instability parameters associated with strong and violent tornadoes,. 2. Variations in the combinations of wind and instability parameters. *The Tornado: its Structure, Dynamics, Prediction, and Hazards. Geophysical Monograph* 79, C. Church, Ed., Amer. Geophys. Union, 583-590.

Johns, R. H., and Dorr, R. A., 1996: Some meteorological aspects of strong and violent tornado episodes in New England and Eastern New York. *Nat. Wea. Dig., 20*, 2-12.

LaPenta, K. D., 1995: Forecasting tornadic versus non-tornadic severe thunderstorms in New York State. *Eastern Region Technical Attachment No. 95-4A*, National Weather Service, NOAA, U. S. Dept. of Commerce, 15 pp.

LaPenta, K. D., and Maglaras, G. J., 1993: New York State tornadoes. *Eastern Region Technical Attachment No. 93-12A*, National Weather Service, NOAA, U. S. Dept. of Commerce, 13 pp.

Maglaras, G. J., and LaPenta, K. D., 1997: Development of a forecast equation to predict the severity of thunderstorm events in New York State. *Nat. Wea. Dig.*, 21, 3-9.

Mahoney, E. A. BUFKIT Documentation,

2001: BUFKIT 3 release 15. [Available from the NWS at www.wdtb.noaa.gov/resources/projects/BUFKIT/index.html].

National Weather Service, 1994: Operational Support Facility, PUP/RPG User's Guide, NOAA, U. S. Dept. of Commerce, 1.1-13.51 pp.

Storm Prediction Center, 2001: SPC tornado frequency tables for Maine, NH VT 1950-1995. [Available from the Storm Prediction Center, 1313 Halley Circle, Norman, OK 73069 and at www.tornadoproject.com/alltorns/ustorns.htm].

Trapp, R. J., E. D. Mitchell, G. A. Tipton, D. W. Effertz, A. I. Watson, D. L. Andra,Jr., and M. A. Magsig, 1999: Descending and nondescending tornadic vortex signatures detected by WSR-88D's. *Wea. Forecasting*, 14, 625-639.

U. S. Department of Commerce, 1994-2001: Stormdata and unusual weather phenomena.

Tables

Table 1. List of all tornadoes across Maine, New Hampshire and Vermont since the network installation of WSR-88Ds in the Northeast (1994-2001). There have been 20 "Recent" tornadoes - 6 F2s, 10 F1s and 4 F0s

1. 6/18/1994....F1...(Saint Francis, ME; 1615 UTC)
2. 6/18/1994...F1...(Caribou, ME; 1715 UTC)
3. 7/1/1994.....F0...(Caribou, ME; 1604 UTC)
4. 7/2/1994.....F0...(Lake Francis, NH; 2200 UTC)
5. 7/23/95........F1...(Meredith, NH; 2339 UTC)
6. 7/8/96..........F2...(Lake Cobbosseecontee, ME; 2100 UTC)
7. 6/21/97........F1...(Rome, ME; 2100 UTC)
8. 7/3/97..........F1...(Swanze, NH; 2313 UTC)
9. 7/3/97..........F2...(Greenfield, NH; 2355 UTC)
10. 7/28/97......F0...(Ft. Kent, ME; 1930 UTC)
11. 8/27/97......F0...(Charleston, ME; 1845 UTC)
12. 5/31/98......F2...(Antrim, NH; 2203 UTC)
13. 5/31/98......F2...(Bennington, VT; 1945 UTC)
14. 10/1/98......F1...(South Paris, ME; 1321 UTC)
15. 7/6/99........F2...(Barnstead, NH; 2027 UTC)
16. 8/13/99......F1...(Plainfield, NH; 2330 UTC)
17. 8/13/99......F1...(Sweden, ME; 0330 UTC)
18. 7/18/00......F1...(Newry, ME; 1800 UTC)
19. 8/9/00........F2...(Cornville, ME; 2303 UTC)
20. 6/17/01......F1...(Newry, ME; 1410 UTC)

	SURFACE	850 MB	500 MB
New England Strong and Violent (F4-F5) Tornadoes (Johns 1996)	(82) 28 (69) 21 190˚	16 12 240˚	-11 -22 260˚
Northern New England F1-F2 Tornadoes	(79) 26 (68) 20 190˚	14 11 260˚	-11 -17 270˚

Table 2. Composite surface, 850 mb and 500 mb data at tornado touchdown. Data is for west mid-level (500 mb) flow regime. Values above composite wind barb indicates ˚F at the surface, otherwise temperatures are in ˚C. Direction of the wind located next to wind barb.

Figures

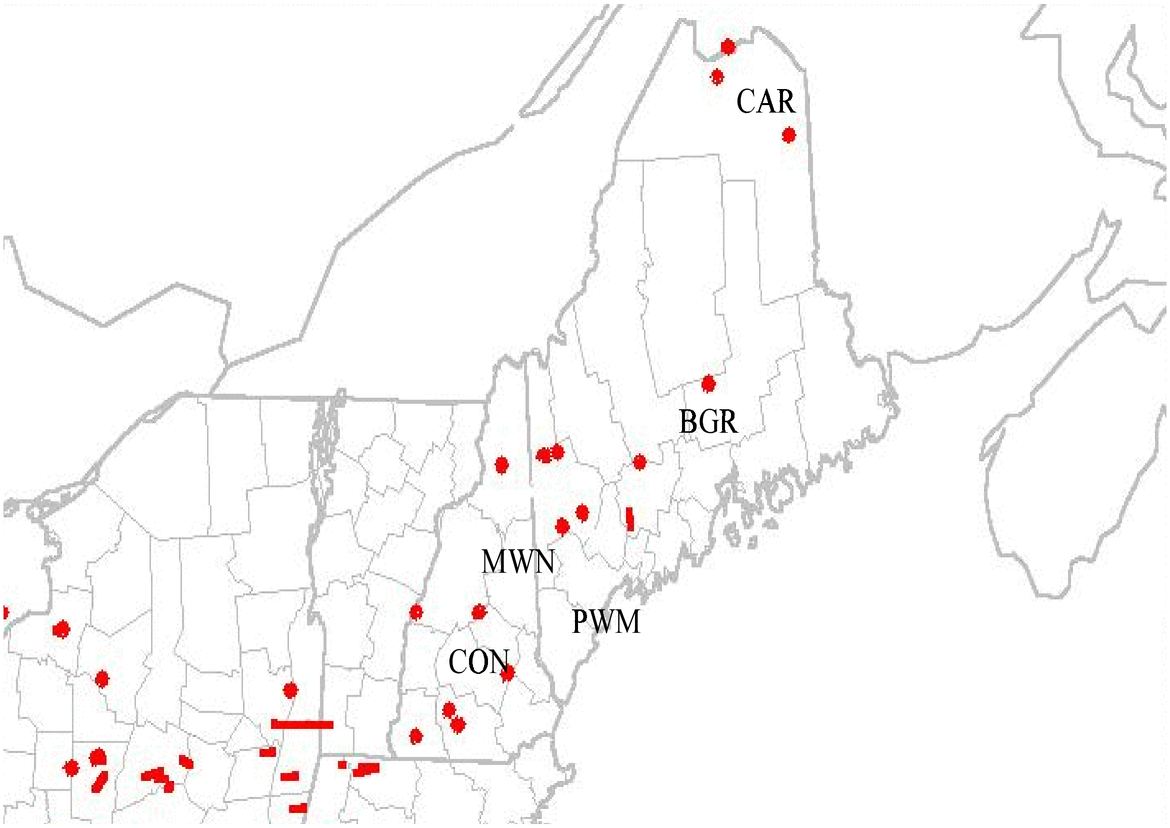

Figure 1. Red lines represent tracks of F0-F2 tornadoes in Maine (ME), New Hampshire (NH) and Vermont (VT) during the period 1994-2001.

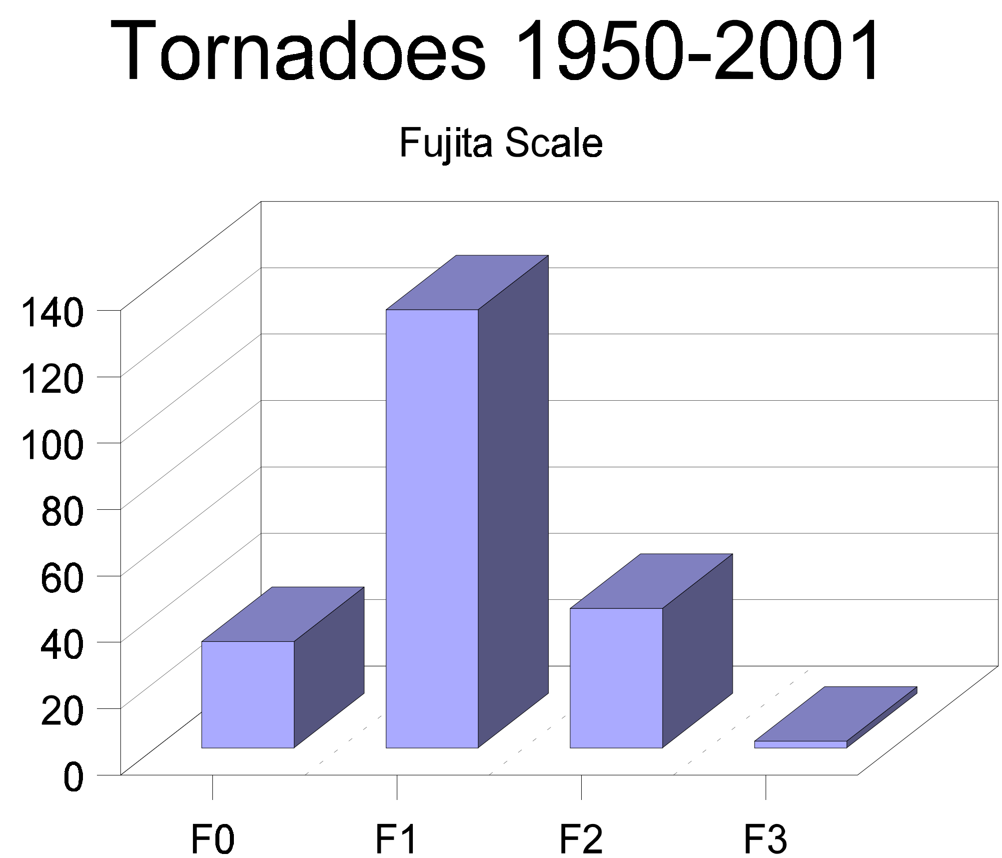

Figure 2. Tornado dmage by F-scale in northern New England (1950-2001). Most tornado damage was classified as weak (F1).

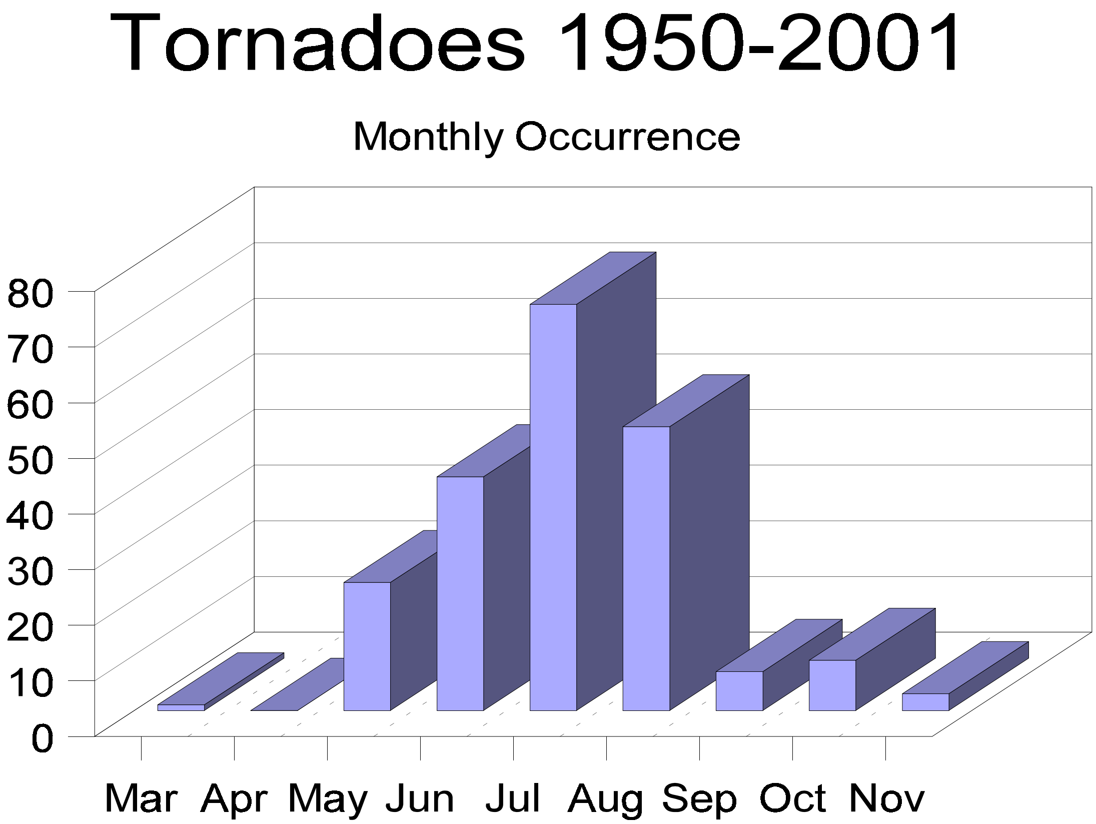

Figure 3. Tornado occurrence by month of F0-F3 tornadoes in norhern New England (1950-2001). Most tornadoes occurred during the meteorological summer (June, July and August).

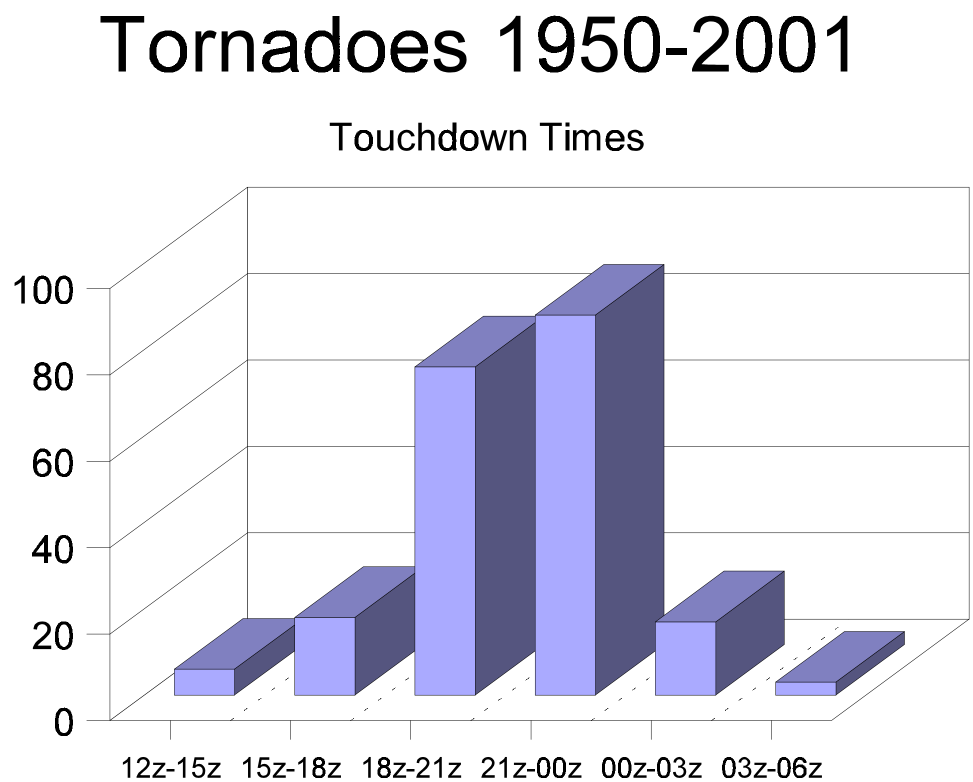

Figure 4. Tornado occurrence by time of day of F0-F3 tornadoes in northern New England (1950-2001). The largest cluster of tornadoes occurred during the mid afternoon through early evening hours.

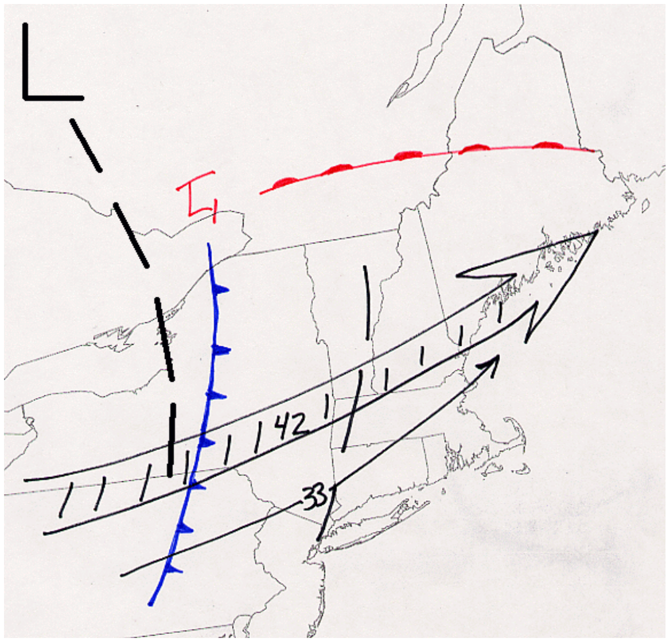

Figure 5. Composite synoptic features associated with west flow at 500 mb for tornado touchdowns in western New England (Vermont and western New Hampshire). For tornadoes in eastern New England (eastern New Hampshire and Maine), synoptic positions shift approximately 100 km further east. Surface frontal and trough symbols conventional. Jet at 500 mb indicated by broad hatched area, with 850 mb denoted by narrow solid line. Darker trough over central New York State denotes position of mean 500 mb trough. Numerical values denote composite wind speed in kts.

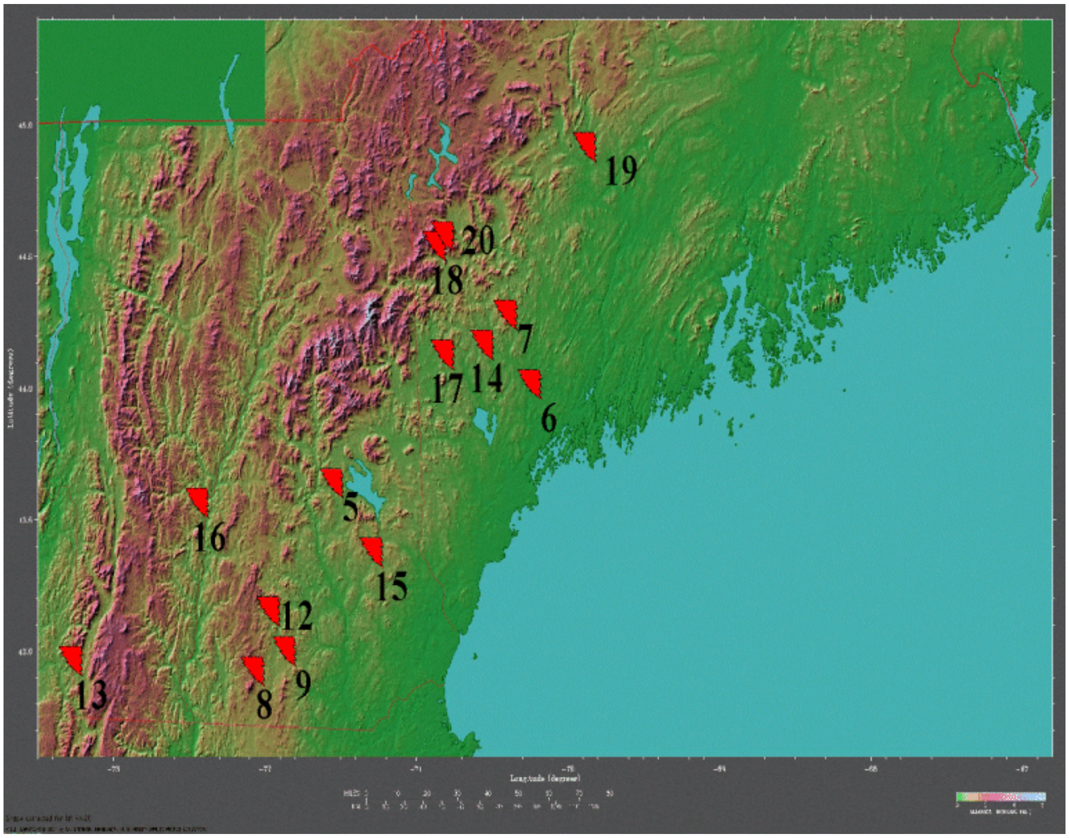

Figure 6. Plot of F0-F2 tornado touchdowns (1994-2001) in Vermont, New Hampshire and southern Maine superimposed on a topographical map (northern Maine not shown). Brown shading is terrain in excess of 1,500 feet. Corresponding numbers refer to tornadoes listed in Table 1.